Inflatable axially contractable actuator.

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Abstract of **EP0219327**

An axially contractable actuator (11) has an inflatable bladder (14) which unfolds on filling with pressurized fluid to contract axially as the volume of contained pressurized fluid is increased. The wall of the bladder is formed by a series of adjoining polyhedral protrusions (15) extending outwardly from the actuator axis, each protrusion having four or more sides and adjoining protrusions being joined at their bases to form folds or seams along substantially straight lines. Each protrusion additionally is foldable along another flexible fold or seam (55) of the protrusion wall in a theoretical plane dividing the respective protrusion into two parts, the protrusions unfolding from an axially extended condition of the actuator, in which they enclose a reduced volume, to an axially contracted condition in which they enclose a larger volume. Optionally, axially aligned end connectors (30) are provided at the bladder ends, and these are joined by linked cables (20) embracing the protrusions along fold lines (55) at the protrusion bases (44).

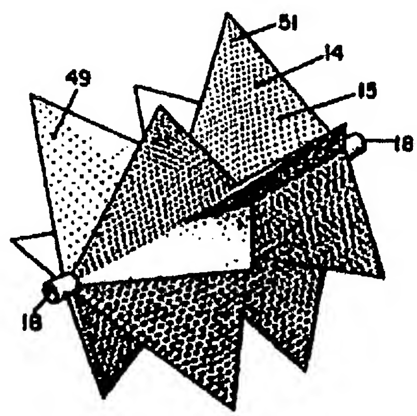

Figure 3

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(54) **Inflatable axially contractable actuator.**

(57) An axially contractable actuator (11) has an inflatable bladder (14) which unfolds on filling with pressurized fluid to contract axially as the volume of contained pressurized fluid is increased. The wall of the bladder is formed by a series of adjoining polyhedral protrusions (15) extending outwardly from the actuator axis, each protrusion having four or more sides and adjoining protrusions being joined at their bases to form folds or seams along substantially straight lines. Each protrusion additionally is foldable along another flexible fold or seam (55) of the protrusion wall in a theoretical plane dividing the respective protrusion into two parts, the protrusions unfolding from an axially extended condition of the actuator, in which they enclose a reduced volume, to an axially contracted condition in which they enclose a larger volume. Optionally, axially aligned end connectors (30) are provided at the bladder ends, and these are joined by linked cables (20) embracing the protrusions along fold lines (55) at the protrusion bases (44).

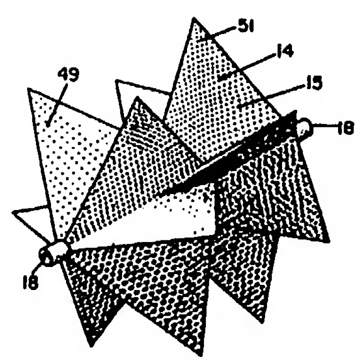


Figure 3

EP 0 219 327 A1

Description

INFLATABLE AXIALLY CONTRACTABLE ACTUATOR

The present invention relates to an inflatable axially contractable actuator and an enclosure for same, inflatable in response to increasing fluid pressure.

Earlier inflatable, contractable actuators designed for providing a selected tension force between two points include United States Patent No. 2,483,088 issued September 27, 1949 to de Haven which is composed of an inner elastomeric tube and an outer tensioning tube composed of strands interwoven on the diagonal, forming a plurality of left-handed and right-handed helices in the shape of a continuous tube. Radially directed force on the helically wound strands is provided by the inner tube in response to increasing the fluid pressure therein. Expansion of the helices translates into overall contraction and resultant tension applied to the actuator end supports.

United States Patent No. 2,844,126 issued July 22, 1958 to Gaylord discloses an elongated expansible bladder made of flexible elastomeric material surrounded by a woven sheath forming an expansible chamber which contracts in length when expanded circumferentially by pressurized fluid. The sheath and end connectors translate radial expansion to axial force on a load.

United States Patent No. 3,654,173 issued February 29, 1972 to Yarlott discloses an elongated flexible thin-walled bladder coupled at either end to coupling member end supports. The bladder expands or contracts radially in response to increased or decreased fluid pressure in the bladder, respectively, translating to axial movement of the end supports from extended or retracted positions, respectively. A network of spaced apart longitudinally-extending inextensible strands coupled by spaced apart inextensible strands embedded in the bladder, prevent elastic expansion of the shell and assist in translating radial force into axial tension.

Russian Patent No. 291,396 issued 1971, discloses a flexible bladder with non-stretchable threads fitted in the tube walls and affixed to an end terminal similar to Yarlott.

In the United States application Serial No. 06600978 filed April 16, 1984 by one M. Kukolj there is disclosed an axially contractable actuator comprised of an open network of linked cables and a flexible non-elastomeric bladder.

An important source of failure of devices such as de Haven arises from rubbing of the inextensible strands on the bladder. Such friction is at a maximum at the start of any contraction or extension due to the static nature of the friction and the requirement to break through this relatively high level of static friction before experiencing a lower dynamic friction. In devices such as de Haven, elastic hysteresis occurs due to expansion of the bladder surrounded by the strands.

The second limitation of some foregoing devices arises because of the relatively limited amount of contraction as a percentage of the uncontracted distance between the actuator ends that such actuators can achieve. The percentage contraction of the de Haven and Gaylord actuators is limited by the need to change the angle of the woven strands in the outer sheath during contraction. The amount of pulling force and the percentage contraction of the axially contractable actuator is directly related to the volumetric expansion of the bladder since the work done by the actuator equals the pressure therein multiplied by the total change in volume inside the actuator. In the above devices, the volume change inside the inextensible strands or cables, is sometimes referred to as the spindle volume.

Although Yarlott, de Haven, and Gaylord refer to a requirement for only flexible material for the bladder, de Haven and Gaylord indicate elastomeric material as being preferable. It has been discovered that operation of devices such as de Haven and Gaylord is enhanced by the lateral forces exerted on the strands as a result of elastic expansion of the bladder between the strands. Unfortunately, the high friction forces on, and tension forces in the fabric at these locations drastically increase the likelihood of actuator failure. With the Yarlott actuator, the possible percentage contraction is limited by the ability of the bladder to accommodate radial bulging without excessive shear stress in the bladder membrane.

In accordance with a first aspect of the present invention, there is provided an inflatable axially contractable actuator bladder having a plurality of substantial protrusions about its periphery, characterised in that each such protrusion has a respective base having at least four sides, each base side of a protrusion is substantially straight and attached to a base side of an adjacent protrusion by a first flexible seam or continuous fold, and each protrusion is foldable about a second flexible seam or continuous fold, said second seam or fold being in a plane dividing the protrusion into two parts, from an axially-extended condition in which the protrusion encloses a reduced volume to an axially contracted condition in which the protrusion encloses a larger volume.

In accordance with a second aspect of the present invention, there is provided an inflatable axially contractable actuator bladder having a plurality of protrusions about is periphery, characterised in that each such protrusion has a respective base having at least four sides, each said base side of a protrusion is substantially straight and attached to a base side of an adjacent protrusion by a first flexible seam or continuous fold, and each protrusion is foldable about a second flexible seam or continous fold, said second seam or fold being in a plane dividing the protrusion into two parts, from an axially extended condition in which the base sides of the protrusion are substantially aligned thereby enclosing a reduced volume to an axially contracted condition in which the protrusion encloses a larger volume.

In accordance with a third aspect of the present invention, there is provided an inflatable axially contractable actuator bladder having a plurality of protrusions about its periphery, characterised in that each such protrusion is a convex polyhedron with a respective base having at least four sides, each said base side of a protrusion is substantially straight and attached to a base side of an adjacent protrusion by a first flexible seam or continuous fold, and each protrusion is foldable about a second flexible seam or continuous fold, said second seam or fold being in a plane dividing the protrusion into two parts, from an axially extended condition, in which the base sides of the protrusion are substantially aligned thereby enclosing a reduced volume to an axially contracted condition in which the protrusion encloses a larger volume.

In accordance with a fourth aspect of the present invention, there is provided an inflatable actuator bladder axially contractable along a main axis and having a plurality of protrusions about its periphery, characterised in that each such protrusion is a convex polyhedron with a respective base having at least four sides, each said base side of a protrusion is substantially straight and attached to a base side of an adjacent protrusion by a first flexible seam or continuous fold, and each protrusion is foldable about at least one second flexible seam or continuous fold, said second seam or fold being in a plane which divides the protrusion into parts and which incorporates the main axis of the bladder, from an axially extended condition in which the base sides of the protrusion are substantially aligned thereby enclosing a reduced volume to an axially contracted condition in which the protrusion encloses a larger volume.

In accordance with a fifth aspect of the present invention, there is provided an inflatable actuator bladder axially contractable along a main axis, having a plurality of protrusions about its periphery, characterised in that each such protrusion has at least four sides and an arcuate outer periphery, each said base side of a protrusion is substantially straight and attached to a base side of an adjacent protrusion by a first flexible seam or continuous fold, and each protrusion is foldable about at least one second flexible seam or continuous fold, said second seam or fold being in a plane which divides the protrusion into parts and which incorporates the main axis of the bladder, from an axially extended condition in which the base sides of the protrusion are substantially aligned thereby enclosing a reduced volume to an axially contracted condition in which the protrusion encloses a larger volume.

The invention further provides a bladder wherein the base sides of the protrusions are substantially aligned when the actuator is axially extended.

The invention further provides such a bladder wherein the protrusions are convex polyhedra.

The invention further provides such a bladder axially contractable along its main axis wherein each protrusion is foldable about at least one second flexible seam or continuous fold lying in a plane which divides the protrusion into parts and which incorporates the main axis of the bladder.

The bladder may include series of protrusions which have base sides at least one end thereof which is not adjacent an axial end of the bladder. The base sides of the protrusions may be equal in number but preferably have an equal number or four or six base sides.

The invention further provides an inflatable actuator including a bladder and a pair of axially aligned end connectors, means for inflating the bladder and means for transmitting tension force in the material of said bladder to axial pulling force at the end connectors.

Provision of a plurality of protrusions articulating about their base seams and sides allows the use of substantially non-elastomeric use material for the membrane of the hollow enclosure or bladder, thereby avoiding failure problems associated with elastomeric materials.

While utilizing properly dimensioned articulating protrusions such as convex four-sided pyramids, increased reliability is obtained due to the minimization of stretching or buckling in the enclosure. Proper dimensioning of the protrusions also allows modification of the characteristic force curve of the actuator.

Advantageously, the hollow enclosure or bladder is made of a flexible material. Utilizing a flexible non-elastomeric material rather than a rigid plate for the protrusions results in a more even distribution of membrane forces over the length of the base seams of the protrusions.

The present invention also provides an actuator as described above, further comprising a pair of axially aligned end connectors, one at each end of the bladder, means for inflating the bladder, and means for transmitting tension force in the material of said bladder to axial pulling force at the end connectors.

By way of example only, specific embodiments of the present invention will now be described, with reference to the accompanying drawings, in which:-

Figure 1 is a perspective view of an actuator and bladder incorporating an embodiment of bladder in accordance with the present invention, in an axially-extended state;

Figure 2 is a perspective view of the actuator and bladder of Figure 1 in a partially axially contracted state;

Figure 3 is a perspective view of the bladder shown in Figure 1 in an axially-extended state;

Figure 4 is a perspective view of the network of linked cables with end connectors of the actuator of Figure 1 in an axially-extended state;

Figure 5 is a perspective view of the bladder shown in Figure 1 in an axially-contracted state;

Figure 6 is a perspective view of the network of linked cables of the actuator of Figure 1 in an axially-contracted state;

Figure 7 is an alternative end connector assembly and an inverted nipple extending inside the bladder;

Figure 8 is another end connector assembly similar to Figure 7;

Figure 9 is a perspective view of a four-sided pyramidal protrusion forming one of several which comprise a bladder;

Figure 10 is a perspective view of a truncated pyramidal polyhedron which is adapted to form one of the plurality of polyhedrons of the bladder;

Figure 11 is a perspective view of the forces on an element of fabric of the bladder;

Figure 12 is a schematic force diagram showing the fabric cable interaction;

Figure 13 is a schematic elevation view of a force diagram on a mesh segment;

Figure 14 is a schematic view of a force diagram showing the forces on an end connector;

Figure 15 is a perspective view of an actuator having protrusions in the shape of four-sided convex polyhedra having an outer surface which is truncated substantially parallel to the base of the polyhedra when the latter is folded flat; and

Figure 16 is a perspective view of an actuator having polyhedra with arcuate outer peripheries.

An actuator 11 shown in Figure 1 in axially-extended form has a network of linked cables 10 which are attached to end connectors 12 and 13. The axial direction extends between connectors 12 and 13. The network of linked cables 10 surrounds a hollow enclosure or bladder 14 preferably made of flexible, substantially non-elastic, impermeable material which is also attached to end connectors 12 and 13. The hollow enclosure 14 which protrudes through apertures of the network of linked cables 10 can accommodate fluid pressure from a gaseous or liquid medium.

The actuator 11 in axially-contracted form is shown in Figure 2.

The hollow enclosure 14, illustrated in Figures 3 and 5 without the network of linked cables 10 and end connectors 12, is preferably made from flexible, substantially non-elastic impermeable material, such as, for example, woven fibres of nylon or kevlar bonded with flexible rubber or plastic to form an impermeable membrane. In Figure 3, the hollow enclosure is in the axially-extended state, while Figure 5 shows it in the axially-contracted state. A tubular nipple 32 and fittings 18 may either be external to the hollow enclosure 14 or internal thereto as shown in Figures 7 and 8. The hollow enclosure 14 has preferably a shape of multiple interconnected convex polyhedra which are in this embodiment approximate four-sided pyramids 15 joined along their basal edges 44, each pyramid having corners 46 extending from the basal edge intersections to an apex 47. The corners 46 are formed by the intersection of adjacent polyhedron faces 48. The hollow enclosure embodiment shown in Figure 3 has two stages 49 and 51 along the actuator axis, each stage comprised of six four-sided pyramids each, for a total of twelve pyramids in all. Other hollow enclosure configurations of more than two stages of convex polyhedra along the actuator axis and fewer than or greater than six convex polyhedra in each stage work well also.

Although a network of linked cables is not necessary to functioning of the bladder 14, Figures 4 and 6 illustrate the network of linked cables 10 and the end connectors 12 in isolation from the hollow enclosure 14 shown together in Figures 1 and 2. The network 10 is comprised of non-stretchable flexible tension links 20 which are joined together at nodes 22 so as to form four-sided diamond-shaped apertures 24 in the network. The cables or tension links 20 are terminated with bulbous fittings 26 which are inserted into sockets 28 and in the end connectors 12 and 13 thus forming a strong connection. Retaining ring 30 serves to hold the bulbous cable terminations 26 into the sockets 28 of the end connectors 12 and to hold the cable elements 20 next to the hollow enclosure 14 as the actuator 11 contracts axially. End connectors 12 and 13 serve to transmit actuator pulling force to a load. End connector 12 also serves to let liquid or gas into or out of the hollow enclosure 14 by means of orifice 16 and a nipple 32 having a hollow interior which is in fluid communication with orifice 16.

Other network designs employ six-sided apertures, for example, are also possible. The network of linked cables 10 is fabricated from multiple-strand steel cables 20 joined together at the nodes 22 with metal compression ferrules. Other materials can be used for the network of linked cables 10, for example, solid wire, pivoted rigid links, joined twine, and synthetic fibres.

Figure 7 illustrates an alternative end connector 42 suitable for tension actuators with a cable network 10 having looped ends 34 thereof attached to the end connector body 36. Threaded cable stanchions 38 serve to transmit the pulling force from the cable elements to the end connector body 36. The retainer ring 40 is internally threaded so that it can be screwed over the end connector body 36. An internal termination 18 to the hollow enclosure 14 is provided for receiving a nipple 32 of the end connector 42. An internal end termination of the hollow enclosure allows shortening of the total length of the actuator 11.

Figure 8 illustrates yet another alternative end connector 43 in which the fluid orifice 23 is at the end rather than running transversely to the axis of the actuator 14.

Referring to Figure 5, the protruding polyhedra of hollow enclosure 14 are four-faced pyramids joined to each other along their basal edges 44 by continuous folds or flexible seams 54. Each face 48 of a pyramid is joined to adjacent faces 48 by flexible lateral folds or seams 55 extending along corners 46. The polyhedra could be truncated pyramids as shown in Figure 10 meeting along a truncated edge 50 having lateral seams 52 and basal edges 57 rather than having lateral seams 55 and basal edges 44 as shown in Figure 9. In the specification polyhedron or polyhedrol is intended to describe complex shapes having sides which are planar or substantially planar. The polyhedra of hollow enclosure 14 need not be all identical nor need they be symmetrical.

The cable network 10 has segments or links 20 which occupy the valleys between adjacent polyhedra. They need not be attached to the hollow enclosure 14, but may optionally be attached thereto embedded in or part of the material of the hollow

enclosure 14.

In operation, the admission through orifice 16 of fluid pressure inside hollow enclosure 14 causes the membrane of the latter to flex and accommodate an increase in volume inside enclosure 14. The expansion of enclosure 14 causes the network of linked cables 10 to expand radially and contract axially as illustrated in Figure 6; thus, the linked cables 10 transfer tension of the membrane of the hollow enclosure 14 to pulling force on the end connectors 12 and 13. The same articulation occurs without the network of cables.

When the actuator 11 is fully extended, each polyhedron is preferably, collapsed to its minimum possible volume which is preferably negligible compared to its expanded volume. As actuator contraction develops, each polyhedron expands its volume by folding articulation along its lateral seams 55. In addition, the polyhedra alter their mutual orientation by folding along their common basal edges 44. The net result is an increase in both radius and total enclosure volume and a corresponding shortening of the enclosure 14. The polyhedra are each dimensioned so that articulation is accompanied by only negligible change in their surface dimensions while also maintaining substantially shear-free connections to each other. Avoidance of deformation in this manner permits the enclosure to be fabricated from impermeable substantially non-elastic impregnated fabric or even from rigid hinged plates. However, the former material is preferable inasmuch as the flexible fabric distributes tension forces over the entire surface area of the enclosure. At full expansion (actuator-contracted), the flexible fabric polyhedra tend to develop a moderately curved or conical form, and the polyhedra faces will bulge with only minimal stretching.

The folding articulation of the polyhedra facilitates contraction of the actuator 11 with only a relatively small change in radius of the portion of the hollow enclosure defined by the basal seams 54 from that in an extended condition to that in a contracted condition. The latter radius change is small compared with the inflatable balloon-like devices having a plurality of longitudinally-extending load bearing cables. The actuator 11 is capable of achieving contractions in excess of 45%. The cable network 10 constrains radial expansion of the enclosure, thereby minimizing deformation as well as relieving interpolyhedra seams of any longitudinal tension. Cable network 10 transmits a large axial force to the end connectors, thereby minimizing axial stress on the enclosure fabric at the end connectors and failure of the enclosure 14.

Figure 5 and Figures 15 and 16 show expanded hollow enclosures (actuator-contracted) without a network or linked cables (illustrated in Figure 6). For small actuators or actuators operating at lower pressure, the network of linked cables is not necessary, since the tensile strength of the hollow enclosure itself is sufficient to transmit pulling forces to the ends of the actuator. Therefore, Figure 5 and Figures 15 and 16 represent further embodiments. If end connectors are employed, they may be similar to those depicted in Figures 4, 7 and 8, but without provision for terminating the cables 10, and without the retaining sleeve 30 and 40.

A theoretical analysis of the actuator 11 involves a force equilibrium analysis as well as an energy analysis. The essential concept of force equilibrium analysis is the transformation of outward pressure force on the polyhedra faces into longitudinal tension force in the cable mesh. Considering an isolated fabric polyhedron, the faces of the polyhedron balance outward pressure force by developing a moderate curvature and internal tension T shown in Figure 11 according to Laplace's formula, as follows:

(1) $2T/R = P$

where:

T = internal tension force per unit width of fabric

R = radius of curvature of the fabric

P = pressure difference between the interior and the exterior of the fabric

Next, considering a cable segment 20 as shown in Figure 12 acted on by the tension force T of adjacent polyhedra faces having an angle 2b between them, the resultant force per unit length F on the cable segment 20 is given by:

(2) $F = 2T \cos b$

Thus, if the polyhedron has a very flat profile, that is, a low apex, then angle b is large and cos b is small, thereby reducing force F.

Force F on the cable segment 30 perpendicular thereto is balanced by the large tension force in the adjacent cable segments as shown in Figure 13 according to the following:

$$FF = \frac{Fs}{M \sin c}$$

where:

FF = adjacent cable segment tension

F = perpendicular force on the cable segment according to Equation 2

c = angle between the cable segment and its adjacent neighbouring segments

M = the numbers of connecting segments at the two ends of the segment under consideration

s = cable segment length

The above formula ignores the small segment curvature and the three-dimensional aspect of the force equilibrium equation.

Finally, considering N cable segments meeting end connector 42 at angle d as shown in Figure 14, the resultant actuator force Fa is given by:

$Fa = N\ FF \cos d$

An energy analysis can equate work done by the fluid interior to the enclosure, to the work done by the contracting actuator on its external end connections because of the minimal elastic strain energy accompanying polyhedra articulation; thus, the force on a load to the end connectors is given by the following:

$Fa = -P\ dV/dL$

where:

V = volume of enclosure

L = length of the enclosure

P = fluid pressure in the enclosure

In this case, a tension force is considered to be positive. For an actuator of original length Lo. Fa is proportional to the square of Lo.

With this second (energy) approach, force versus contraction, maximum contraction, etc., can be determined by computing the geometrical behaviour of the articulating enclosure as it contracts. Articulation with minimal deformation can also be ensured by testing specific polyhedra designs in this computation. Generally, very large forces are achieved at small contractions, and less forces at large contractions. By appropriate choice of numbers and forms of polyhedra, one can tailor specific aspects of actuator behaviour, such as maximum contraction, magnitude of axial force, and radial size, exhibiting a versatility which distinguishes the present actuator from other tension actuators. Specific designs can be obtained which exhibit greater than 45% maximum contraction.

An alternative configuration for the protrusions of an actuator bladder is illustrated in Figure 15 in which the protrusions are in the form of convex polyhedra having six faces and a four-sided base wherein the top of the polyhedra are truncated in a direction substantially parallel to the base when the polyhedra are folded flat. The protrusions in Figure 15 are similar to the one illustrated in Figure 10.

Yet another alternative configuration for the actuator bladder is illustrated in Figure 16 in which the protrusions consist of a four-sided base 72 and an arcuate periphery 74 extending from one corner of the base to a diagonally-opposite corner thereof in a direction substantially axially of the actuator.

Other variations, departures and modifications lying within the spirit of the invention and scope as defined by the appended claims will be obvious to those skilled in the art.

Claims

1. An inflatable axially contractable actuator bladder (14) having a plurality of protrusions (15) about its periphery, characterised in that each such protrusion has a respective base having at least four sides (44), each base side (44) of a protrusion is substantially straight and attached to a base side of an adjacent protrusion by a first flexible seam or continuous fold (54), each protrusion is foldable about a second flexible seam or continuous fold (46, 55), said second seam or fold being in a plane dividing the protrusion into two parts, from an axially extended condition in which the protrusion encloses a reduced volume to an axially contracted condition in which the protrusion encloses a larger volume.

2. An inflatable axially contractable actuator bladder (14) having a plurality of protrusions (15) about is periphery, characterised in that each such protrusion has a respective base having at least four sides (44), each said base side (44) of a protrusion is substantially straight and attached to a base side of an adjacent protrusion by a first flexible seam or continuous fold (54), and each protrusion is foldable about a second flexible seam or continuous fold (46, 55), said second seam or fold being in a plane dividing the protrusion into two parts, from an axially extended condition in which the base sides (44) of the protrusion are substantially aligned thereby enclosing a reduced volume to an axially contracted condition in which the protrusion encloses a larger volume.

3. An inflatable axially contractable actuator bladder (14) having a plurality of protrusions (15) about its periphery, characterised in that each such protrusion is a convex polyhedron with a respective base having at least four sides (44), each said base side (44), of a protrusion is substantially straight and attached to a base side of an adjacent protrusion by a first flexible seam or continuous fold (54), and each protrusion is foldable about a second flexible seam or continuous fold (46, 55), said second seam or fold being in a plane dividing the protrusion into two parts, from an axially extended condition, in which the base sides (44) of the protrusion are substantially aligned thereby enclosing a reduced volume to an axially contracted condition in which the protrusion encloses a larger volume.

4. An inflatable actuator bladder (14) axially contractable along a main axis and having a plurality of protrusions (15) about its periphery, characterised in that each such protrusion is a convex polyhedron with a respective base having at least four sides (44), each said base side (44) of a protrusion is substantially straight and attached to a base side of an adjacent protrusion by a first flexible seam or continuous fold (54), and each protrusion is foldable about at least one second flexible seam or continuous fold (46, 55), said second seam or fold being in a plane which divides the protrusion into parts and which incorporates the main axis of the bladder, from an axially extended condition in which the base sides (44) of the protrusion are substantially aligned thereby enclosing a reduced volume to an axially contracted condition in which the protrusion encloses a larger volume.

5. An inflatable actuator bladder (14) axially contractable along a main axis, having a plurality of protrusions (15) about its periphery, characterised in that each said such protrusion has at least four sides and an arcuate outer periphery, each said base side (44) of a protrusion is substantially straight and attached to a base side of an adjacent protrusion by a first flexible seam or continuous fold (46, 55), and each protrusion is foldable about at least one second flexible seam or continuous fold, said second seam or fold being in a plane which divides the protrusion into parts and which incorporates the main axis of the bladder, from an axially extended condition in which the base sides of the protrusion are substantially aligned thereby

enclosing a reduced volume to an axially contracted condition in which the protrusion encloses a larger volume.

6. An actuator bladder as claimed in any of claims 1 to 5, wherein each said base side includes at least one end thereof which is not adjacent an axial end of the bladder.

7. An actuator bladder as claimed in any of claims 1 to 6, wherein said protrusions have substantially the same number of base sides.

8. An actuator bladder as claimed in claim 7, wherein said protrusions have an even number of base sides.

9. An actuator bladder as claimed in claim 8, wherein said protrusions have four base sides.

10. An actuator bladder as claimed in claim 8, wherein said protrusions have six base sides.

11. An actuator comprising an inflatable bladder as claimed in any of claims 1 to 10, further comprising a pair of axially aligned end connectors, one at each end of the bladder, means for inflating the bladder, and means for transmitting tension force in the material of said bladder to axial pulling force at the end connectors.

12. An actuator as claimed in claim 11, wherein the force transmitting means comprises a network of linked cables embracing the bladder attached to said end connectors.

13. An actuator as claimed in claim 12, wherein the cables are nonintegral with the enclosure and extend over the base seams of said protrusions.

14. An actuator as claimed in claim 13, wherein said end connectors comprise a plurality of longitudinally extending spaced apart cable stanchions for receiving cable loops from ends of said linked cables and which pass between said stanchions and loop around ends thereof. and a nipple protruding from the end of said connector for snug reception of said bladder, and a retainer ring for engagement over said stanchions so as to lock the cable loops in place around said stanchions, and to hold cables next to the bladder.

15. An actuator as claimed in claim 14, wherein one of said nipples has a hollow interior and is in fluid communication with a fluid orifice in said connector for coupling to a source of pressurized fluid.

16. An actuator as claimed in any of claims 12 to 15, wherein said linked cables are each terminated with an enlarged fitting and said end connectors include corresponding sockets radially spaced apart for reception of respective said fittings and a retainer ring for engagement over the ends of said cables for retention thereof to said end connector.

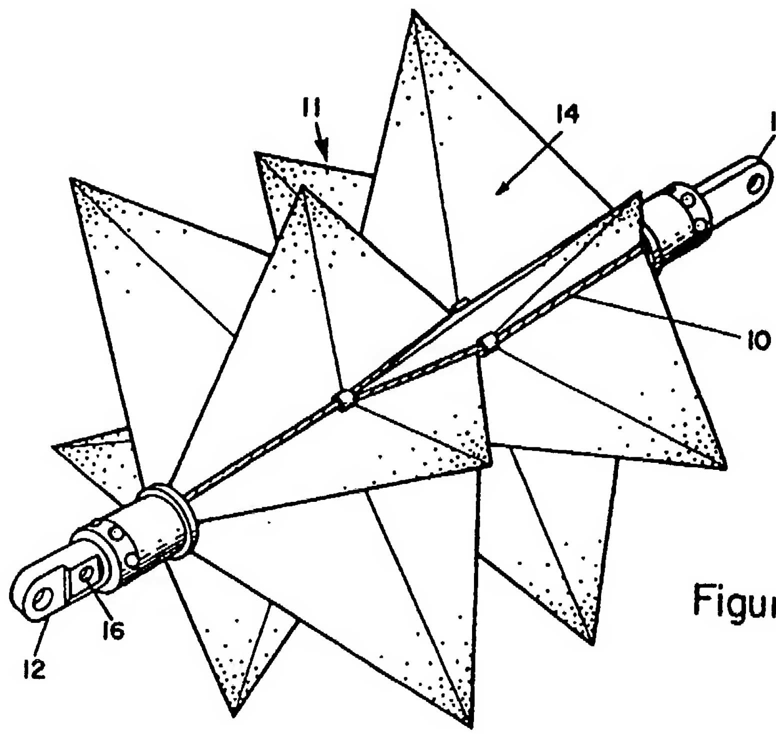


Figure 1

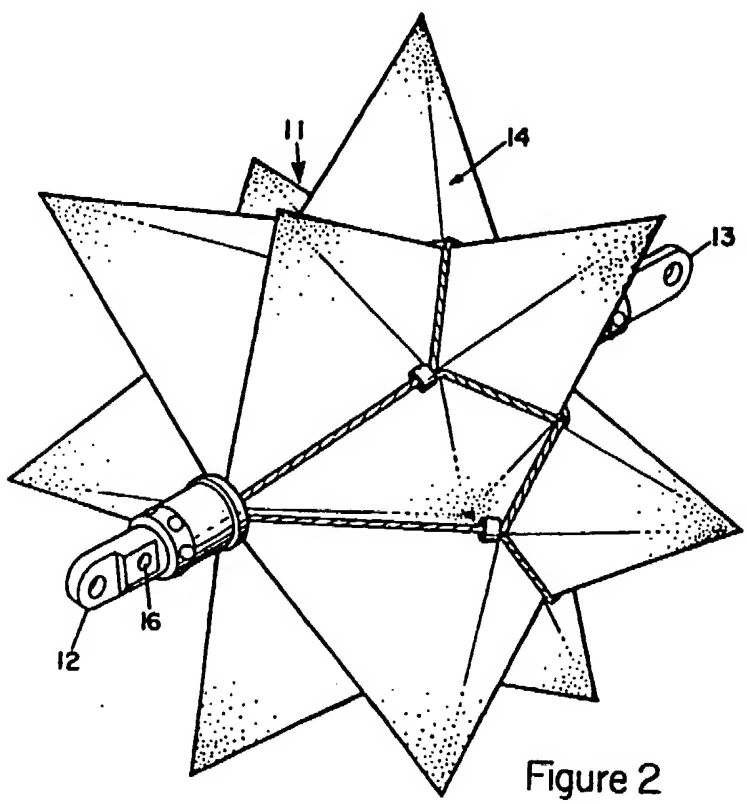


Figure 2

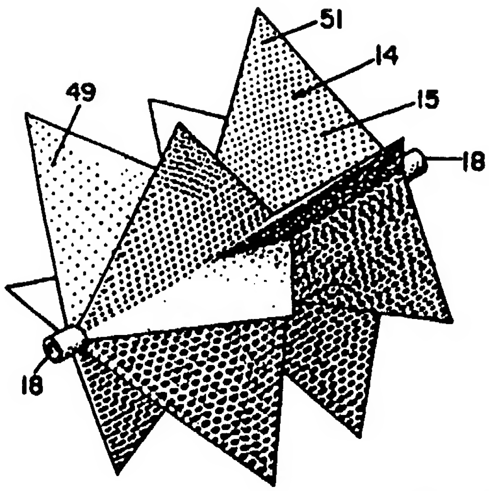


Figure 3

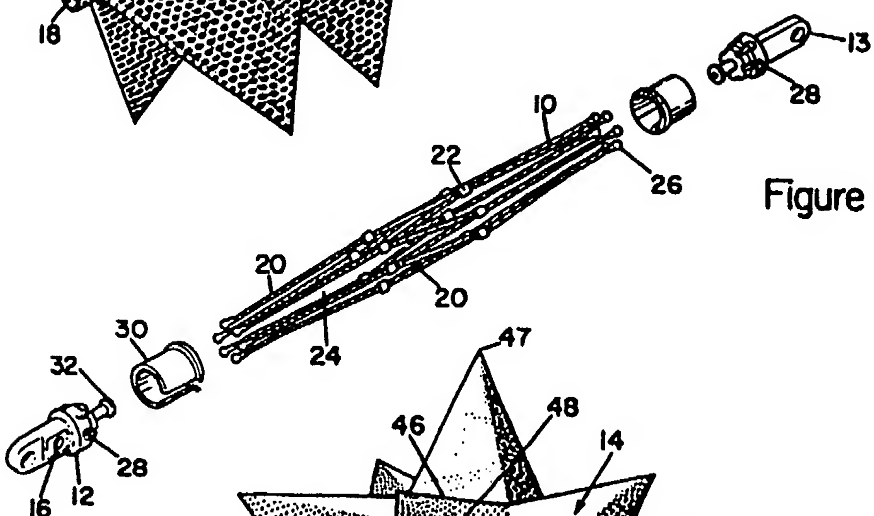


Figure 4

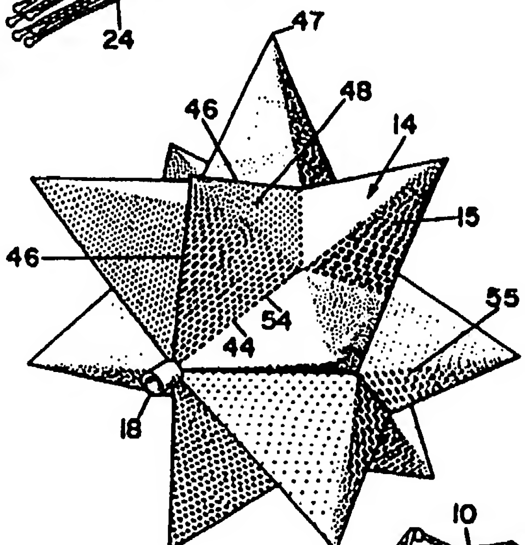
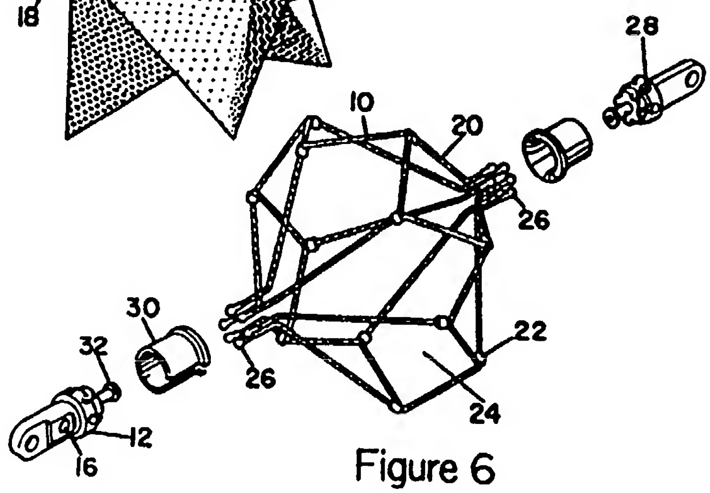


Figure 5



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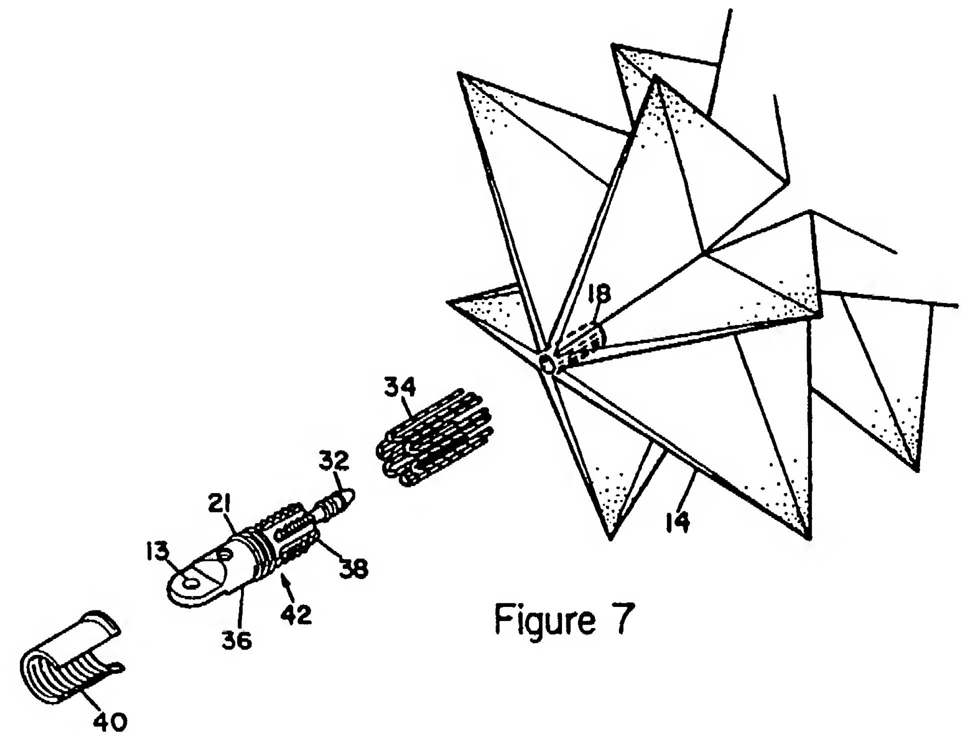

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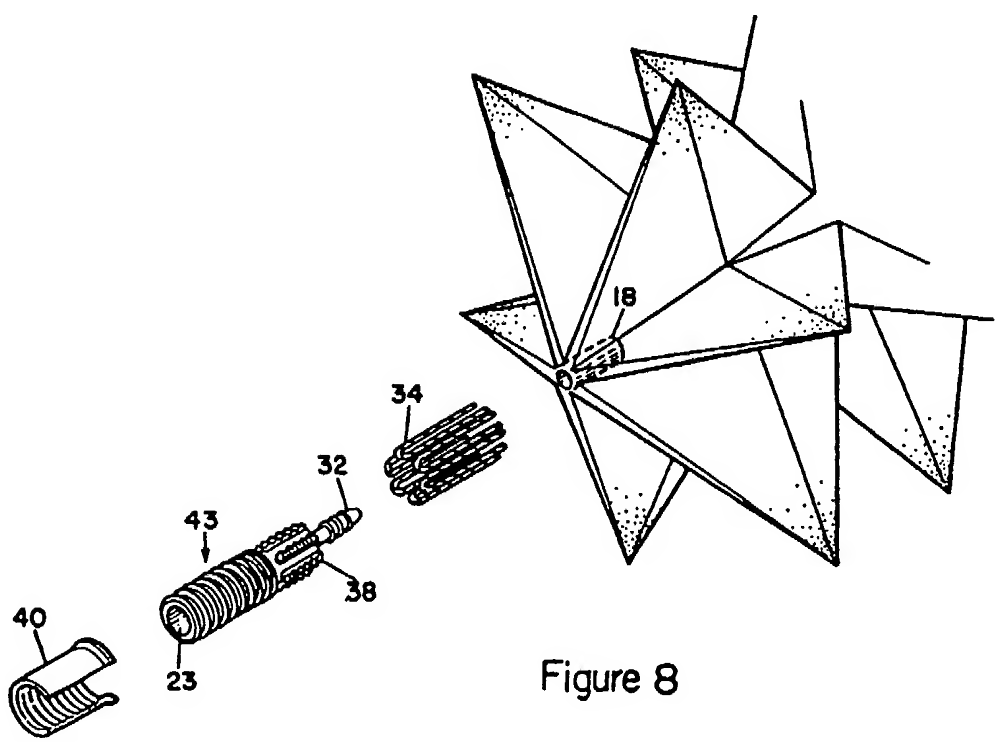
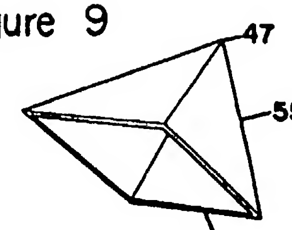


Figure 8

Figure 9



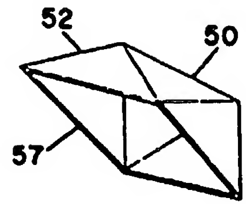


Figure 10

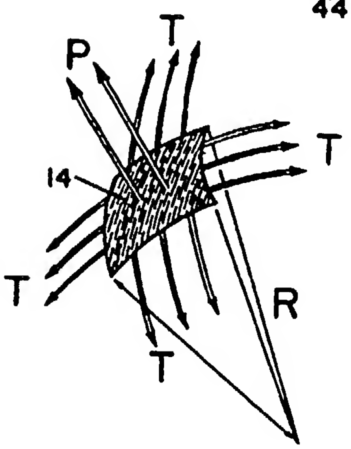


Figure 11

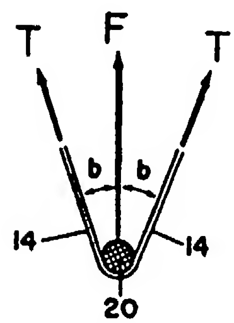


Figure 12

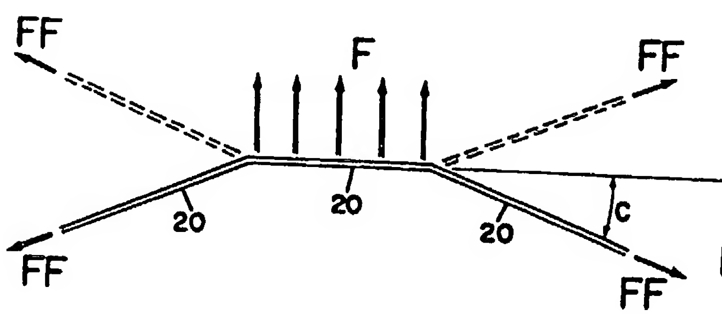


Figure 13

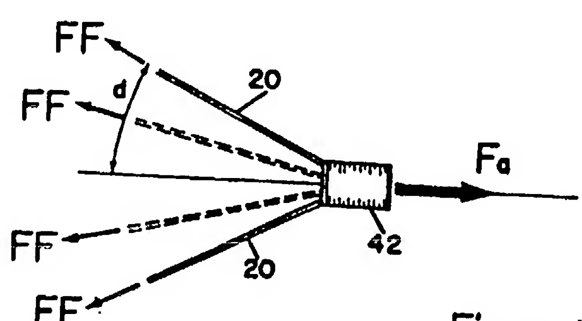


Figure 14

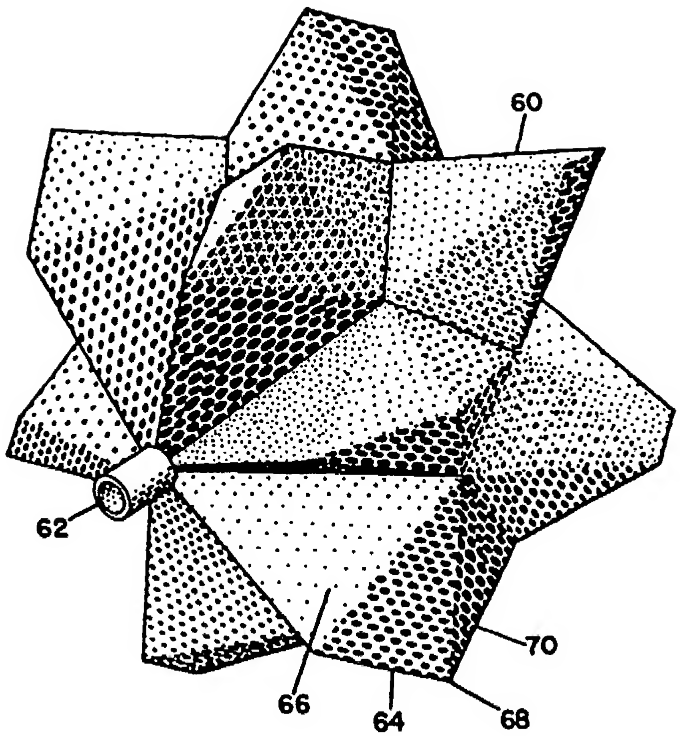


Figure 15

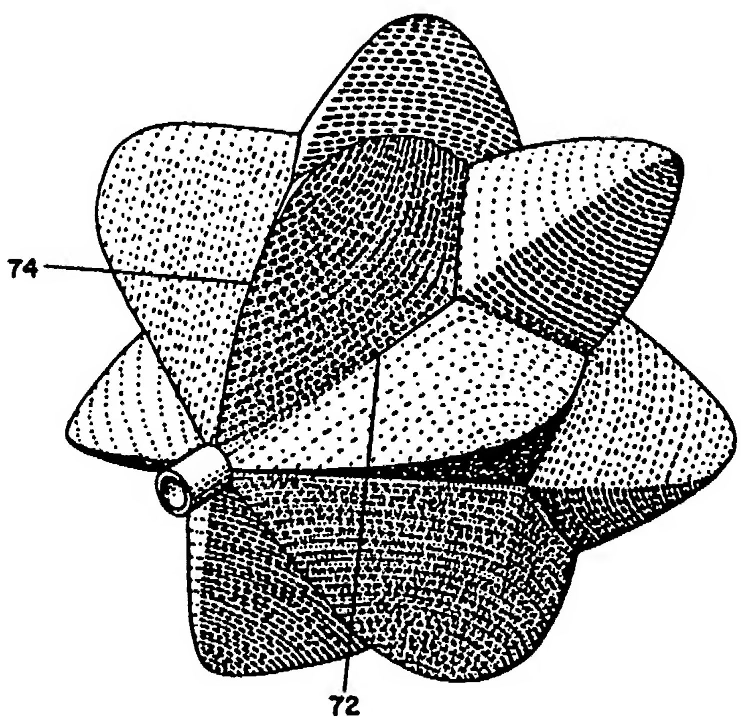


Figure 16

European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 86 30 7860

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	US-A-3 570 814 (ZUPPIGER) * Column 1, lines 65-70 * -----	1	F 15 B 15/08
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
			F 15 B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	14-01-1987	KNOPS J.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
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P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
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